STRESS CONTROL OF MULTILAYER SUSPENDED MEMS STRUCTURES IN HIGH CONTRAST MICROSHUTTERS

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The microshutter array (MSA) is a programmable field mask (Fig. 1) that enables large-format multi-object spectroscopy at extremely high contrast ratios of over 10^5 in space [1]. Assessment of the first generation MSAs used on the James Webb Space Telescope (JWST) revealed light leakage and stuck shutters due to warping (Fig. 2) [2]. Such leakage is partially reduced with appropriate light shields and mitigation strategies. Anticipation of stricter performance requirements for the upcoming Habitable Worlds Observatory Flagship [3] motivates the study. In this paper, we present the systematic study of film stress effects using finite element modeling (FEM) and analysis of newly fabricated MSAs. We present structural designs to mitigate stress effects and improve flatness of suspended structures in micro-electromechanical systems (MEMS). Our study aims to provide a comprehensive view of film-to-film interaction, mechanical, and structural considerations in design and process definition that goes beyond NGMSA devices. The presented findings can be of value to the stress and morphology control in any suspended MEMS membranes.

Figure 3 shows the Next-Generation MSA (NGMSA) design [4]. The shutter blade is a multilayer structure consisting of a silicon nitride structure, an aluminum electrode, and molybdenum nitride (MoN) magnetization stripes. During fabrication specially developed techniques are used to achieve flatness in the wafers. However, without MoN strips, disordered warping will occur due to residual stresses. The MoN helps define the direction of the deformation and improves MSAs from disordered warping to consistent bow shapes with bow height up to 10 µm.

To push the optical performance of MSAs beyond current capabilities, it is desirable to further increase blade flatness. A redesign of the warp control structures is therefore investigated to reduce bow curvature. Our simulations show that the contour of the deposited MoN plays a significant role in the redistribution of stress to the shutter blade surface. Stress tends to be locally concentrated near patterns with curved edges, as can be seen in Fig. 4(b). MoN structures with strategically selected shapes and sizes are selected to demonstrate the difference in stress mitigation effects. The original JWST design, shown in Fig. 4(c) and (d), with sharp corners, does not provide redistribution of the film stresses. Therefore, we maximize the radius of the rounded corners of the original MoN strip design (Fig. 4(e) and (f)). We also explore breaking the strips into two rows and find it creates multiple horizontal high stress lines on the blade surface (Fig. 4(g)). We expect that these locally high stress lines will act as fortified “beams” to control the direction and magnitude of deformation of the blade. Finally, designs with arrays of MoN dots, as shown in Fig. 4(h), are found to drastically reduce blade deformation to submicron levels. It is to be noted that buckling behavior is not taken into consideration in the FEM simulations, and it remains to be seen if unexpected warping will happen to the designs with reduced asymmetry. For this purpose, we select different designs to go into fabrication curated for several purposes: to verify the predictability and accuracy of the model simulation, to study the physics of stress distribution by spluttered decorative films, and to find the design that yields the flattest and most reliable shutter blades. Fig. 5 shows the finalized mask with 18 selected MoN designs. We intend to include these experiment results in the final paper submission.

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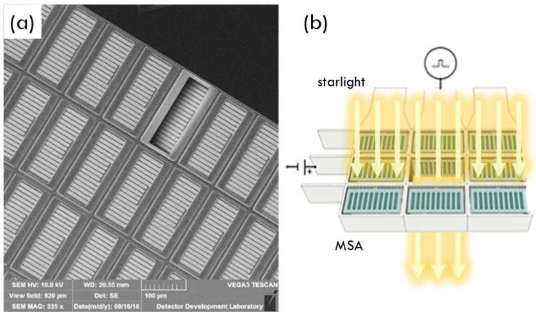

Figure 1. Operating principle of a microshutter Array. (a) Scanning electron microscopy demonstrating one partially opened shutter. (b) Electric 2D-addressing selectively opens individual shutters to allow light to pass through.

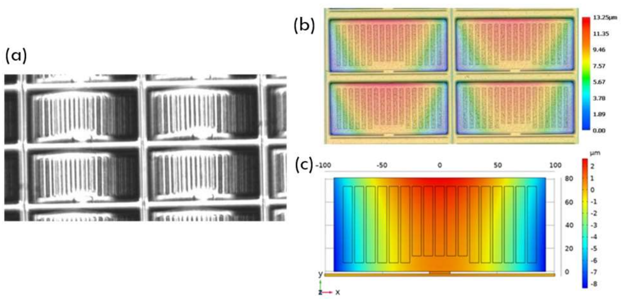

Figure 2. Film stress effect on shutter blade topology. (a) SEM of an array with bowed shutter blades. (b) Optical measurement of a microshutter blade shows more than 7 µm dip near the torsion bar corners and near 6 µm protrusion at the far edge of the blade. (c) Finite element simulation of the original shutter blade confirms the observed effect.

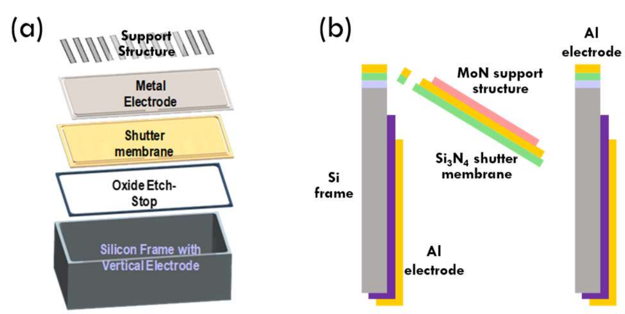

Figure 3. Schematic of a microshutter cell construction. (a) Exploded view of material layers in a microshutter cell. (b) Side view of a partially opened microshutter in a cell element.

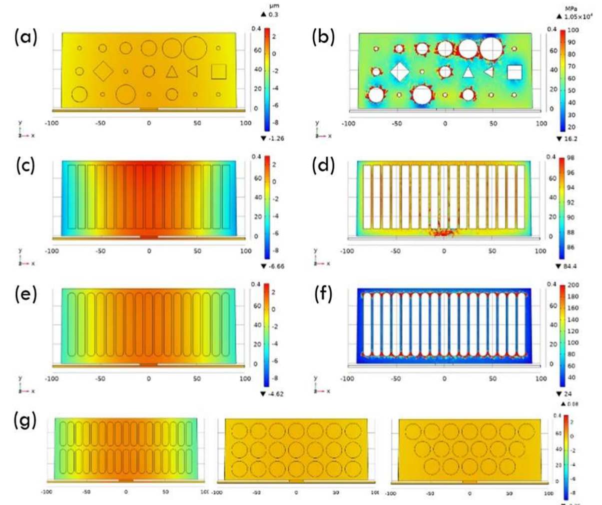

Figure 4. Selected MoN support structure redesigns illustrating their effects on stress distribution and shutter blade flatness. (a)(b) "Sprinkled" shapes. (c)(d) Original strip design. (e)(f) Modified stripe design with rounded corners. (g)-(i) Example of redesigns to be tested with blade flatness improvement to sub-micron levels.

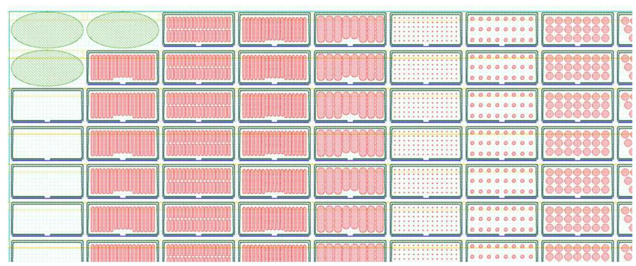

Figure 5. Closeup of the mask redesign for the fabrication of the test array showing a variation of selected MoN support structures.

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